ENGINE CASE EXTERNALS
CHALLENGES AND OPPORTUNITIES

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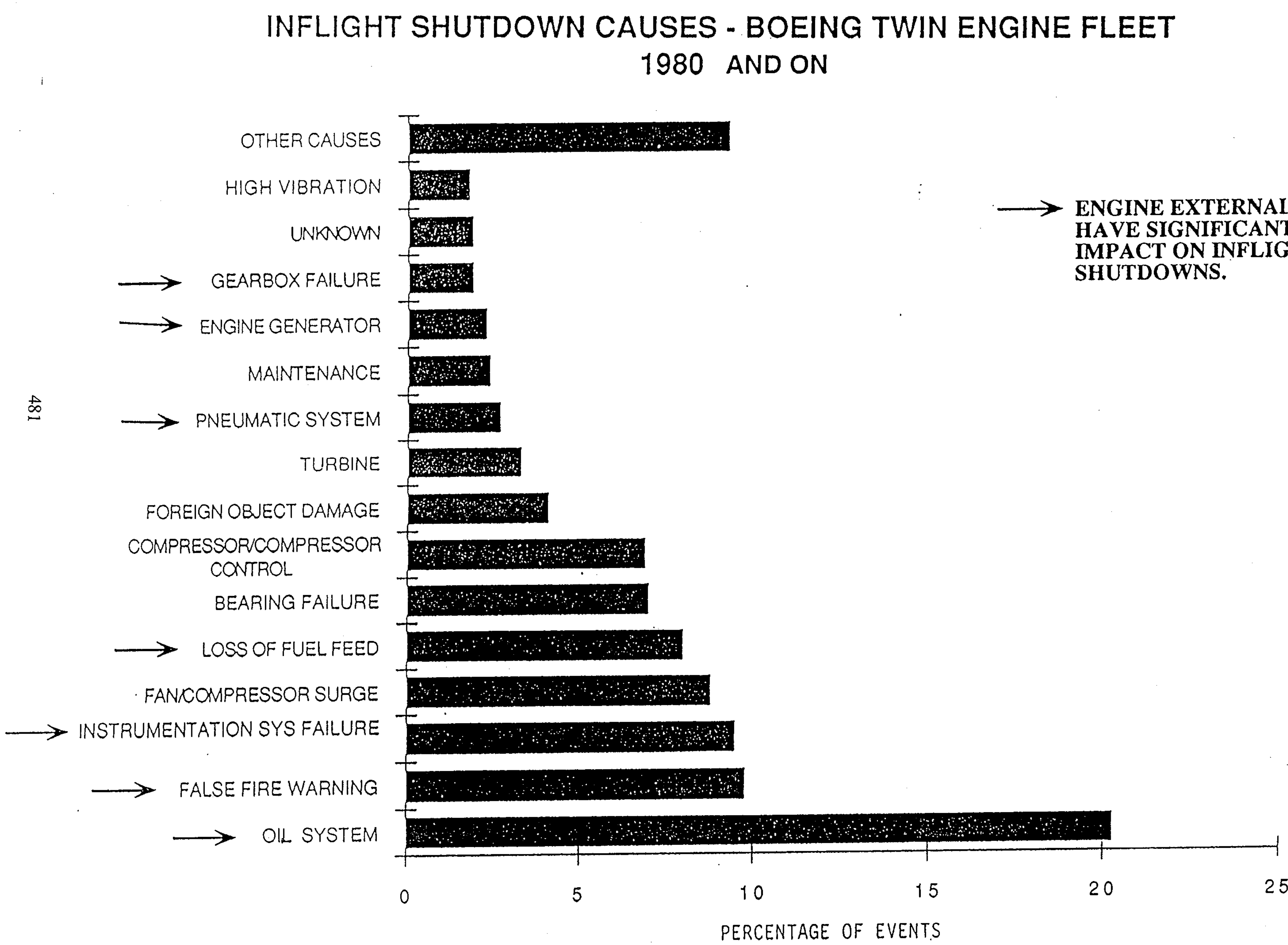
This is technology that we've developed about five years ago when we were designing the engine installation on the 777 .. and it's what we call fly through, and because we had a digital design we could play around with it before we cut any metal and could look at it in all sorts of ways. You could take rides down oil lines and go through seals as you went through the engine nacelle - after awhile we found a use for it on the 737 X and learned how to model manicans for mechanics and put them in place to do routine maintenance work and make sure the components could all be changed out before we cut any metal. And low and behold what we did was reduce the cost of removing and replacing an engine from 11 hours to 4 hrs on the 737, which no-one ever did before....I got the external design responsibility, but I'm presently the Assistant Chief Propulsion Engineer for the 777 program so I have an assortment of three different engines from the original engine configuration of the 777, three more engines of around ninety thousand pounds of thrust, and three more engines again of one hundred thousand pounds of thrust... so we're upto our eyeballs in this business.....Now what does all of this have to do with seals? Well I'm going to show you that we have a lot of seals on these engine cowls.....and the fact is that I want a much better technology standardbecause I'd like to take a physical model like this and combine it with a structural model and be looking at the seal deflections, flow fields, leakages and thermal characteristicsand their effects on performance before we cut any metal....So where I think we ought to be headed is to go into the field of virtual reality with seal design, development andtesting instead of fooling around figuring it out after the fact.... We've even found that you can not design a seal into a nacelle after you have fixed the nacelle design lines - the only way you can put a seal into a nacelle and make it work is if you design the seal first before you let the aerodynamists shape the nacelle and I got that message from a lot of you engine guys here today.... Now I have another cross to bear, because I'm one of your customers and I see some of the these so called seal disasters. We have 767 and that's fine, we have the 767 which had an engine in the first month of service we - had a major failure in the middle of the engine which is called shaft failure, basically it was maybe a 6 hour engine - it was a very badly design bearing and loading arrangement - its very poor at accepting the aluminum oxide particles which a designer had used for sealing in some other part of the engine and it was a disaster. I had an APU on the Air Force One that had to fly at cruise altitude, as a result of the APU running inder these same conditions, the first time we flew it, within 25 minutes, all the oil was gone out of the aft bearing compartment. So, I sympathize with our Allied Signal Friends and their Oil Sealing Problems, and its not a new problem - but it's a long term problem; even last weekend, I spent the whole weekend working on a problem where seals caused a secondary structure failure on the 777 engine in service last week, was diverted to Frankfurt and landed with only 4 quarts of oil, and I spent the whole weekend working on this and providing the test program. Now that's what I want to talk to you about, the opportunities and the challenges - now here we go. This paper was thrown together last week, at Bob's request - he was kind enough call me up a few weeks ago and say "why don't you come up and fill in the deficiency of having an externals guy"? I do feel like I am out of the water here. I really think you ought to have a lot more externals people here. The other fellow on this paper is Jeff Colehour, he's done alot work for NASA Lewis over the years, he is one of our leading nacelle aerodynamists, but externals as you know cause a high proportion of in flight shut-downs - here we have the worst systems at the bottom, oil systems false fire warnings, instrumentation failures, loss of fuel feed - all those with the arrows are externals and some of those without arrows are also part of externals. Now there are a lot of pressures, constraints and questions about these on exploring design . I can go down the list and really keep you from cocktail hour but, you'll see even in the area of maintenance we have things that are very much driven by your intent to produce better sealing. Let me flip this chart over because this shows you which of these things are effected by sealing design and cooling approaches, leak identification - real problems for maintenance people and real problems for me and my externals. I want that case to be sealed real well. Now take something like engine non-containment, we have an engine which has core cooling schemes that with a single failure which would cause the core to overheat and I would have to handle a third of the desk about this big (50 -inch diameter) like a buzz-saw right in the middle of the of the airplane. I believe that you people in the sealing business should produce simple schemes that are safe, put safety at the top of the list and performance much farther down the pecking order, for you have no idea what I have to do to the airplane to protect against bad design and I do have to protect the airplane against that. The engine externals presents a minefield of challenges - its not axisymetric wonderland. O.K. I'm just going to list a few (opportunities) to remind you and I could talk to you for a long time, but since I'm not going to be here that long, you have to be prepared. If we could get our arms around these things they can give us the opportunities for tremendous benefits in performance, reliability, marketing, competiveness, maintenance and functionality, and there are alot of them shown here. I will take about two or three of them today. The one's I've selected to talk about today are Cowling Seals, Component Cooling, Fire Extinguishing and my favorite topic which is the 700 Hundred Degree Wiring. O.K. now cowling seals, very important in airplane performance, not as important as case seals, but certainty they have their effect. For example in the case of the 777 engine one square inch of leakage area is worth 300 lbs of OEW (operating empty weight) so we say to ourselves that, regardless, 6.8 in.^{2} Arepresents about 2000 pounds of OEW, now that 's a few passengers left behind. Now over the years we have been getting little better to go back and look at the leakage area as function of the percentage area of the nozzles, on these fan nozzles the early CFM56 engines on the 737 were about 4/10th of a percent - the most recent design which we're going to roll out this year and flight test next year is about 1/10th of a percent. Now how do we get there? Look at the 777 which is about 0.15 (% nozzle area) is a dramatic improvement over the 747 which I won't tell you what it is because I'm ashamed of what the number is, it's so high on the original 747. Now here is a 777 thrust reverser half, you can't see all the structure in the cascade vanes and actuators and everything and that's what you need - because we need to have straight or circular things to work with, with as few corners as we can get away with. You know on the (technical 777 ?) nacelle, we got 81 feet of seals on the thrust reversers alone, enough for a large leakage area, an that number of square inches of 6.8 sounds like a pretty impressive performance - matter of fact, we do better than that we've got it down to 5, now how did we do that? Well, we did it by trial and error, we built ourselves a basic rig and simulated the engine and the intefaces and we pressurized the nacelle with calibrated flow in ducts and found out where it was leaking and went in and fixed it and kept working on it till we got the 5 square inches and we quit. But I would much rather not do that, I would much rather be there even before I build anything; I want tools, I want the combination of flow tools, the design tools and the structural deflection tools to give us the answer before we cut any materials. This is Component Coooling, and the core compartment surrounding the engine where we have a lot of hardware, it's a nightmare on a typical P&W engine because all their gear boxes are mounted there. One of the main issues with it from the component point of view, of course you have the engine case temperature itself, and any leakage that you happened to give me, you've got the cowling heat transfer which can be beneficial or it can be terrible it depends on how much acoustic treatment is present and how it is made, whether it's made of composite (polymer) or aluminum honeycomb or whether it's a stringer/sheet design we've got the ventilation exit flow field, and I'll show you what I mean by that in a moment - you've got the inlet configuration performance and then component packaging, by that I mean how does the air get through all this mess of tangled wires and spaghetti and bits and pieces built about the engine case? We've got computation capability, yet limits our ability to analyze it - the way we get to do it is by stage averaging and I insist the guys add on a 100 degree's in the hot end, for the local conditions, and 50 degree's in the short end - and it works, more or less.

The real complexities of the thing - by the way this is a nice piece of work that NASA did, it's a program we use for flow projection which was derived from one your programs here at NASA Lewis - this is a P&W power plant engine nacelle for 777, these are pressure relief doors which happened to have vent slots in them, and this right in ~7 ? the back of the (spot ?) is vent slot through which we allow all of the coolant flow from the compartment cooling system, all the flow from the precooler exhaust, turbine case cooling air, all of the coolant systems and all the coolant air runs through. Now we could really mess up the external flow on the nacelle itself if you don't do an intelligent job of this and this is a dual flow field and you'll see two little triangles one called - slots pressure in the relief doors - and one called - aft gap - and that's where the cooling flow comes from and we didn't do a good job, by the way the top picture is a the condition that sizes the precooler, nice and cold at 22000 feet, and the bottom one is at cruise and you can see the shock patterns in the flow flields that we have to exhaust into. If we do not do a very good job we could case the flow to separate from the cowling in that area. So that had to be integrated into the internal cooling flow analysis and its a very complicated business. Now, I say we did a reasonable job because the way we can do it today, the only problem is that it takes me a bunch of tests to get me there and then the 777 on those three engines we spent something in the order of fifteen tests, I don't mean flights, I mean test configurations changes to get to be where we needed to get certified on all three of them and that's a lot of money for us . So there's a lot of mileage in there to improve the understanding of the heat transport problems between the cowl and the engine case and the engine externals. In that same area we see a wonderful opportunity for analysis and for fire extinguishing . On the typical certification program your going to fire something like thirty bottles of agents before you get the fire extinguishing systems correct. In fact on the P&W engine on the 777 we spent a month down in Florida on the engine stand and then another two weeks in Seattle on an airplane stand and it costs us an arm and leg to get the answers right. What we want is a method which will get us there by analysis so that I don't have to go out there to run all these tests, there's other stuff out there which I'm not going to go over with you for we don't have the time and I don't want a method that is going to cause me to run three Cray computers continuously for a month to get one data point. I want an anwer that is going to get my test costs down and then I don't care about this.

I told you that 700 degree-F Wiring is a favorite with me. There is alot of high temperature wiring and worry involved with fire detectors, we have to have wires that won't absorb moisture because the operation of fire detectors depends on its resistance to ground. So we have to path wires that will last in a vibration environment which won't absorb moisture, good for the temperatures that we are now going to see. Now I showed you a plot earlier which said they were seeing temperatures of over 600 degrees. Wiring today isn't capable of that. The airlines know that because when the engines come into the shop they just throw the harnesses away and put new ones on. We are working on a new wiring standard. On the 737 program, the new ones coming out, I've got the wiring finally up to 600 degrees F and I want to go to 700 and that takes me out of the polymer range and takes me into a whole new technology. And not just the wiring but the connectors also. Now I do have a piece of 700 degree wire that is arriving in my office this week that we're going to start testing on. We have an agressive program and we really need industry in a program like this. I think it would be an excellent one for the NASA Agency and for NASA Lewis to put this together. Bas~cally, a 756 engine has these wiring zones where the challenge is at the hot end and that is true in all engines.

So, in conclusion, I would like the research community to review the opportunities outside the engine case, not just those inside the engine case. In fact the two ought to be dealt with together, as an integrated whole. I can tell you this, I've got turbine people that get on my case about giving them cold spots that give them distortion. I never saw any measured data on distortion, that really justifies their means and I think more turbine designers are worried about it then the engine cases themselves are worried about it. The fact is, we have an integrated system and I dump all this preconditioned cold air on the engine case deliberately, cause I don't want to put a slot anywhere except at the aft end of the nacelle. The airframers are meeting the challenges with expensive test and development programs and I think they need to step forward with another level of analysis capability in this whole industry.


INFLIGHT SHUTDOWN CAUSES - BOEING TWIN ENGINE FLEET
1980 AND ON
OTHER CAUSES
HIGH VIBRATION
UNKNOWN
GEARBOX FAILURE
ENGINE GENERATOR
MAINTENANCE
PNEUMATIC SYSTEM
TURBINE
FOREIGN OBJECT DAMAGE
COMPRESSOR/COMPRESSOR CONTROL
BEARING FAILURE
LOSS OF FUEL FEED
FAN/COMPRESSOR SURGE
INSTRUMENTATION SYS FAILURE
FALSE FIRE WARNING
OIL SYSTEM
0
5
10
15
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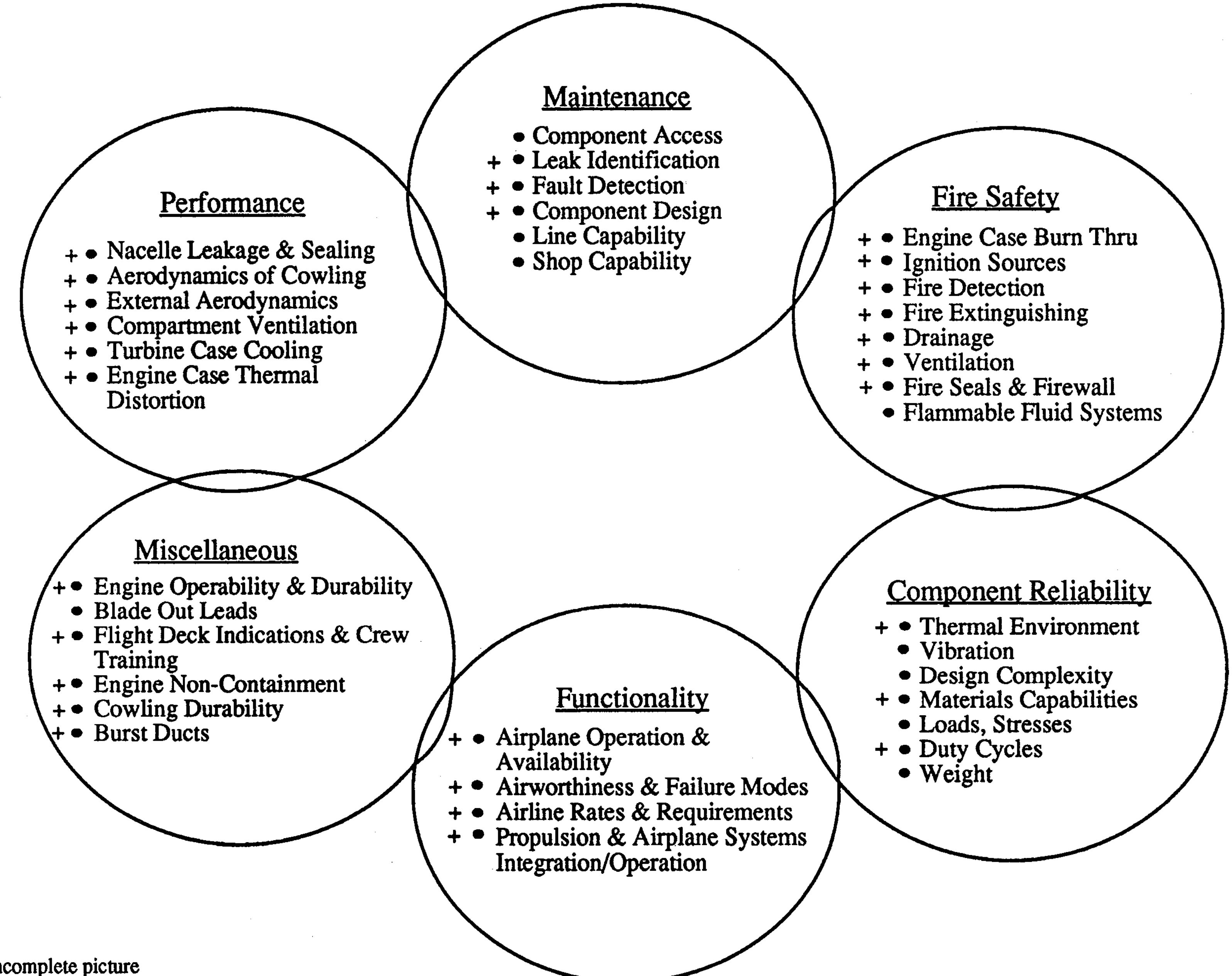
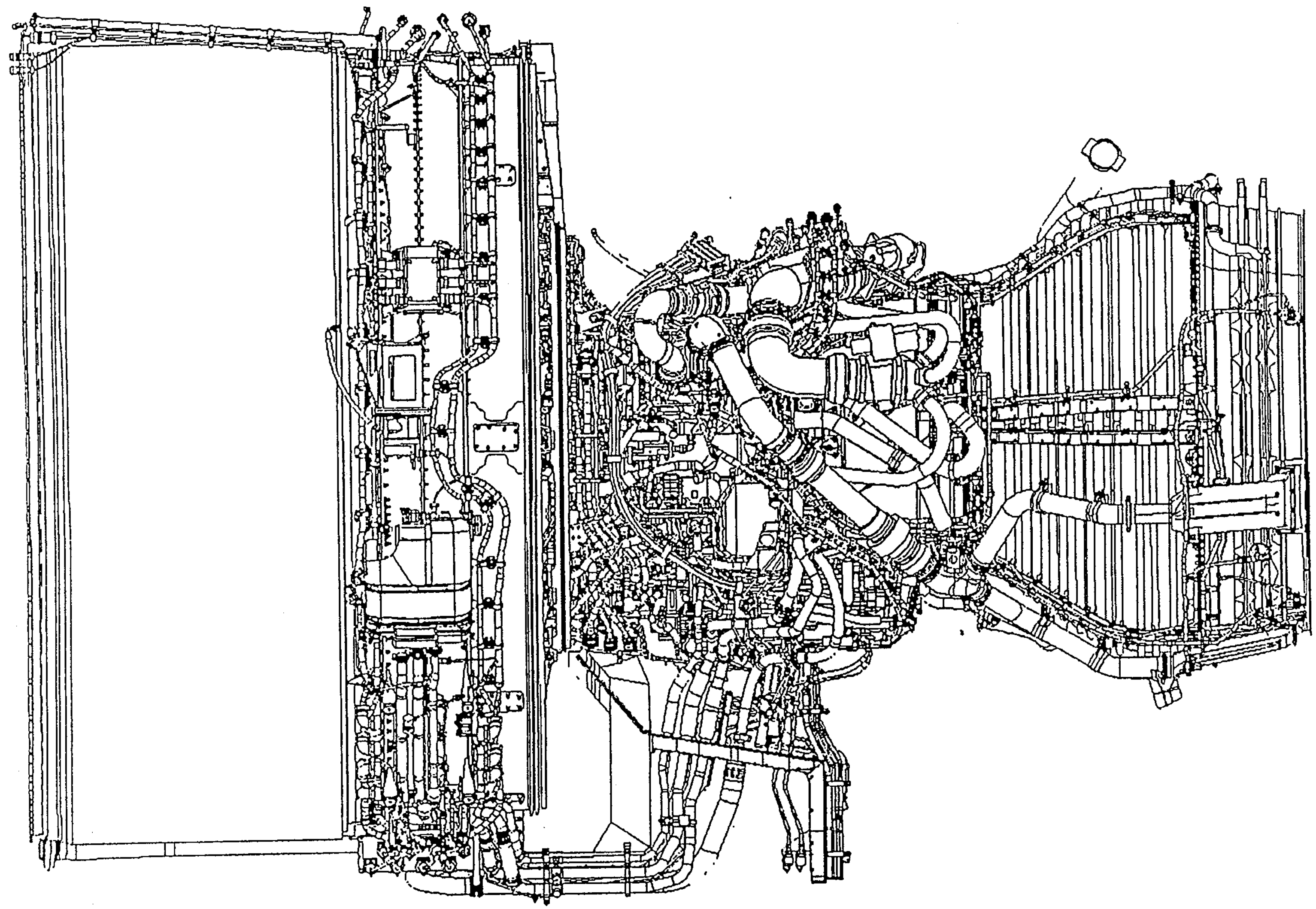
25
PERCENTAGE OF EVENTS
ENGINE EXTERNALS HAVE SIGNIFICANT IMPACT ON INFLIGHT SHUTDOWNS.

EXTERNALS' PRESSURES AND CONSTRAINTS*



* An incomplete picture
\+ Seal/secondary flow opportunities & challenges

ENGINE EXTERNALS - A MINEFIELD OF CHALLENGES



TECHNOLOGY OPPORTUNITIES* - ENGINE EXTERNALS

- High temperature seals
- Ventilation local flows
- Components capable of 700°F
- Pressure relief for burst ducts
- Reliable oil systems indications
- Flammable fluid leakage prevention
- Ice & water detection
- Cowl leakage
- Materials, materials, materials
- Ventilation exhaust into shock fields
- Composite cowls/blankets for high temperatures, vibration and moisture resistance
- Optical fire detectors
- Fire extinguishing prediction
- Blade out loads
- Fuel system cavitation
- High temperature electronics
- Heat transfer analysis

IMPROVED

Performance, Reliability, Market Competitiveness, Airworthiness, Maintenance Costs, Functionality

* An incomplete list

EXAMPLE OF EXTERNALS' CHALLENGES

- Cowling Seals
- Component Cooling
- Fire Extinguishing
- 700°F Wiring & Connectors

COWLING SEALS

- Leakage Impacts
- Leakage Goals
- 777 Nacelle Aerodynamic Seals
- 777 Leakage Area
- Test Fixture

IMPACT OF FAN DUCT LEAKAGE ON ENGINE PERFORMANCE

- Loss of fan flow results in fan gross thrust reduction in proportion to leakage flow.

- For typical 777 engine:

  (Leakage per nacelle, OEW & TSFC per airplane)

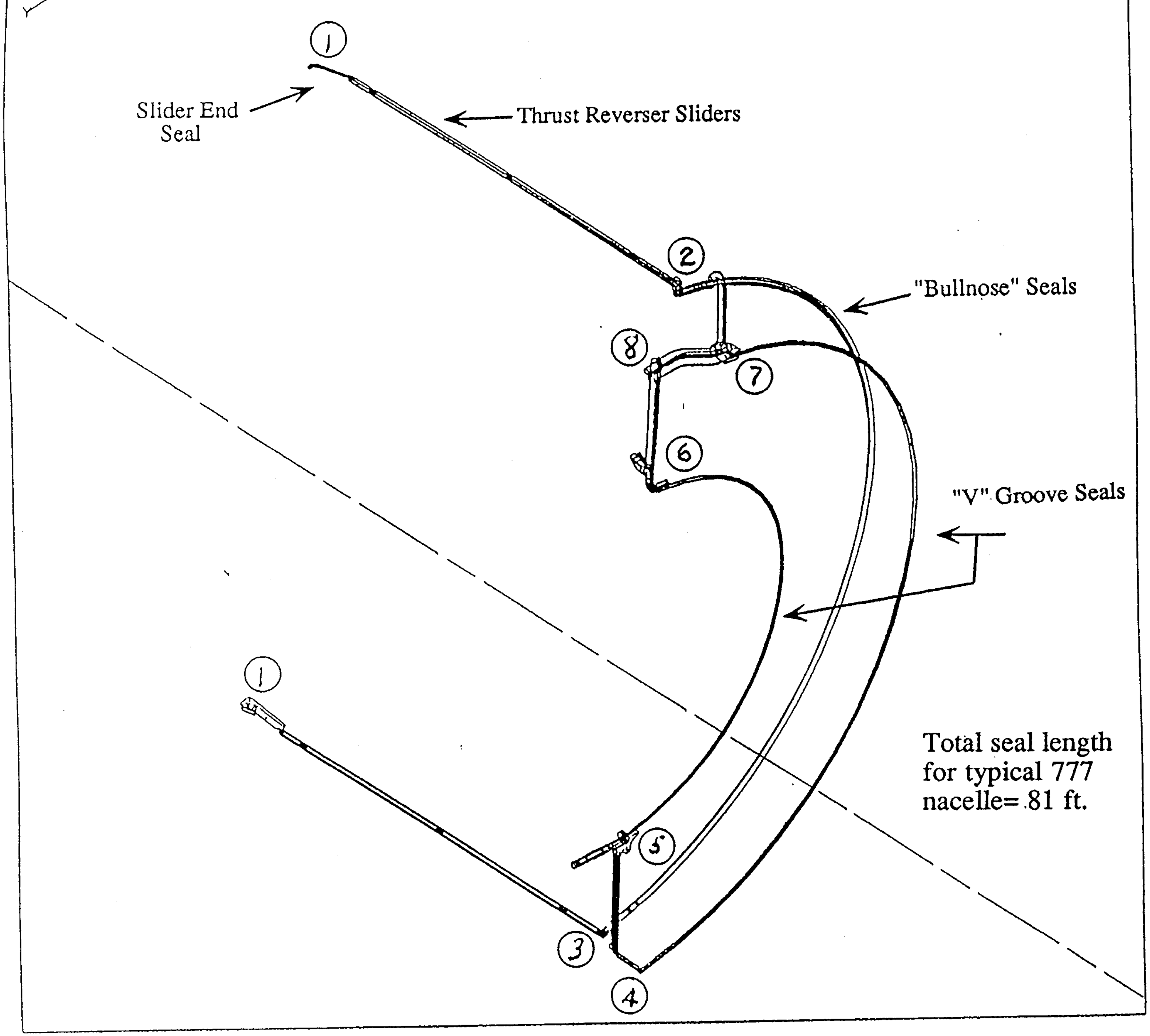
  1 in^2 effective leakage area = 300 lb OEW = 0.056% ΔTSFC

  Target 777 leakage = 6.8 in^2 = 2040 lb OEW = 0.38 % ΔTSFC

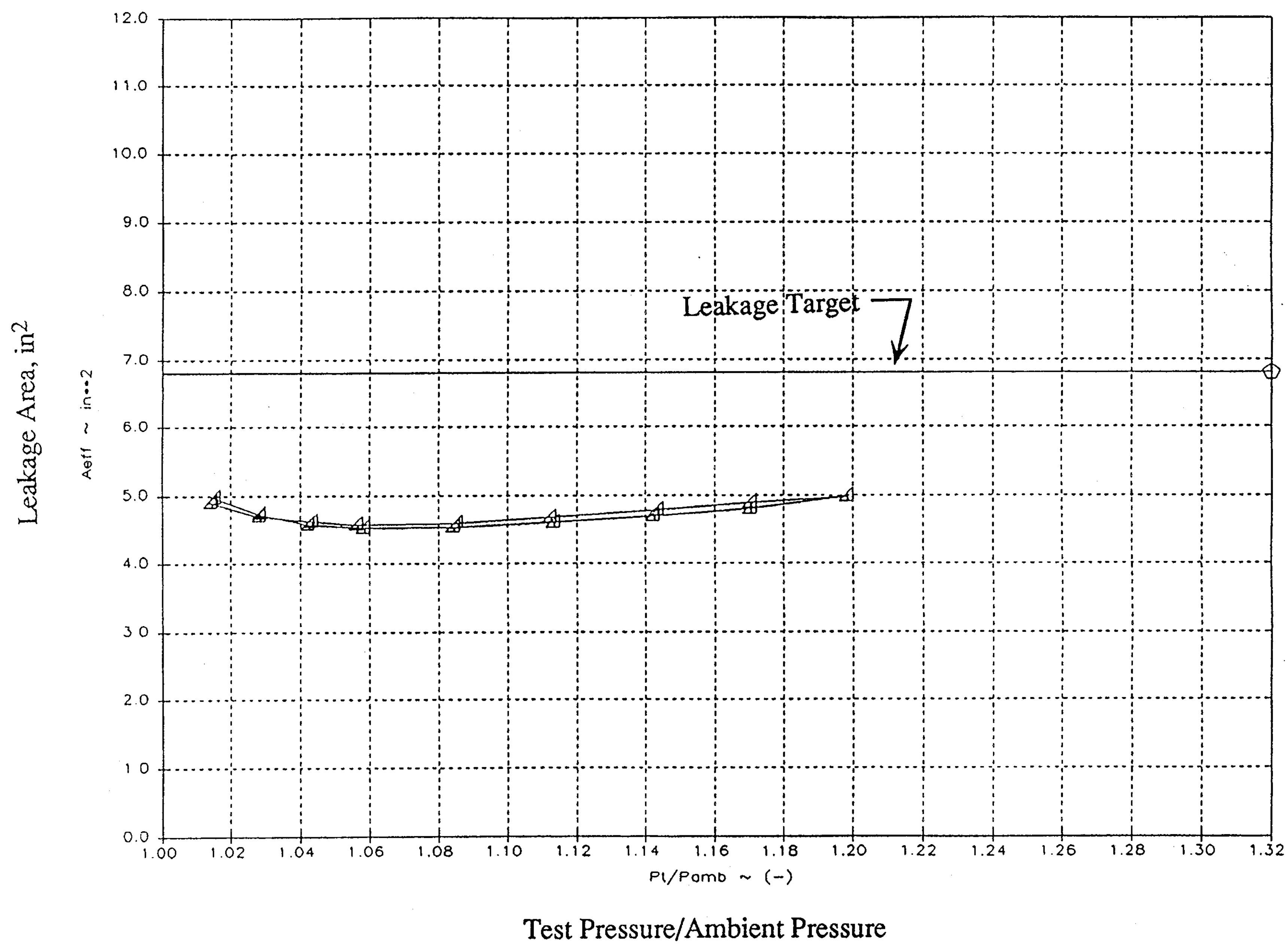
LEAKAGE GOALS FOR CURRENT NACELLES (TYPICAL)

Airplane	Nominal Fan Nozzle Area in^2	Target Leakage Area in^2 (% of Nozzle Area)
737-300/400/500	1160	4.64 (0.40%)
757-200	2143	3.2 (0.15%)
767-200/300	2783	4.2 (0.15%)
777-200/300	4533	6.8 (0.15%)
737-600/700/800	1200	1.2 (0.10%)
747X	4400(Goal)	4.4 (0.10%)

777 AERO SEALS



TYPICAL 777 NACELLE LEAKAGE TEST DATA



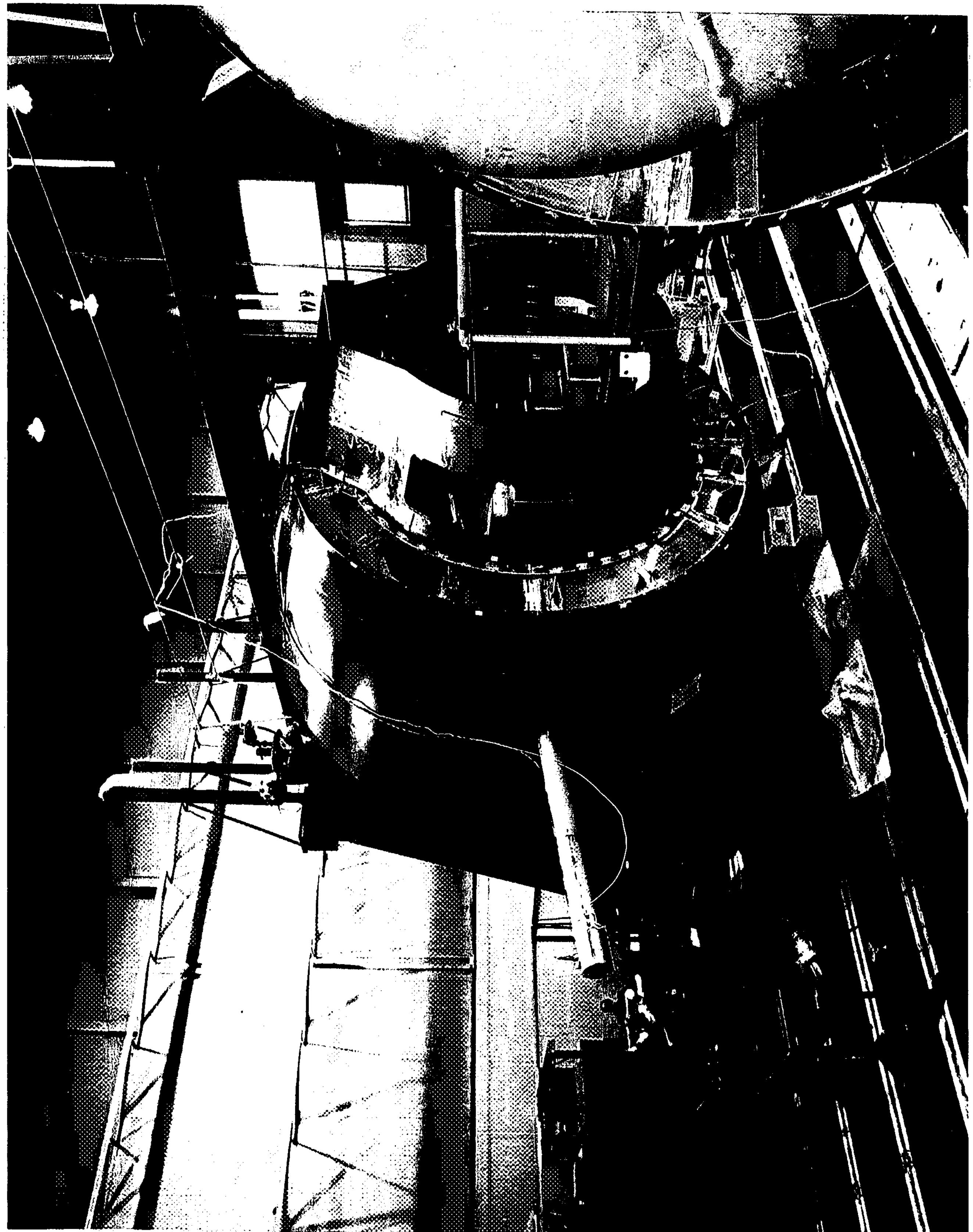


Photo No. 1: View of W6003 LH in Test Fixture
Note: View is from LH Aft Quarter. LH "BullHorn" is visable on T/R side.
(Ref. Photo Lab No. 294-277)

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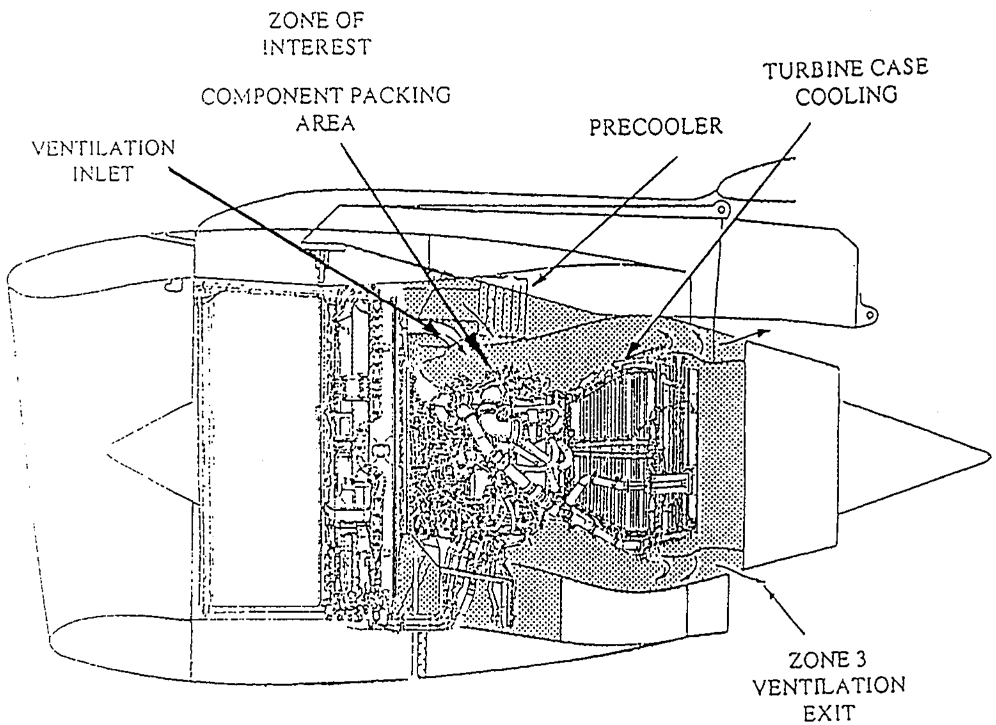
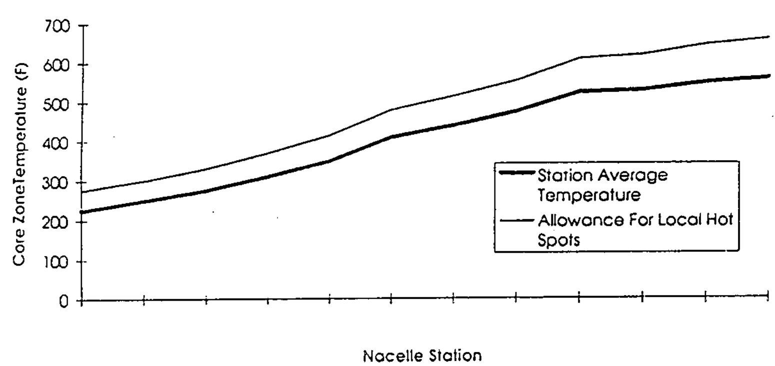
Attachment A

Component Cooling Analysis

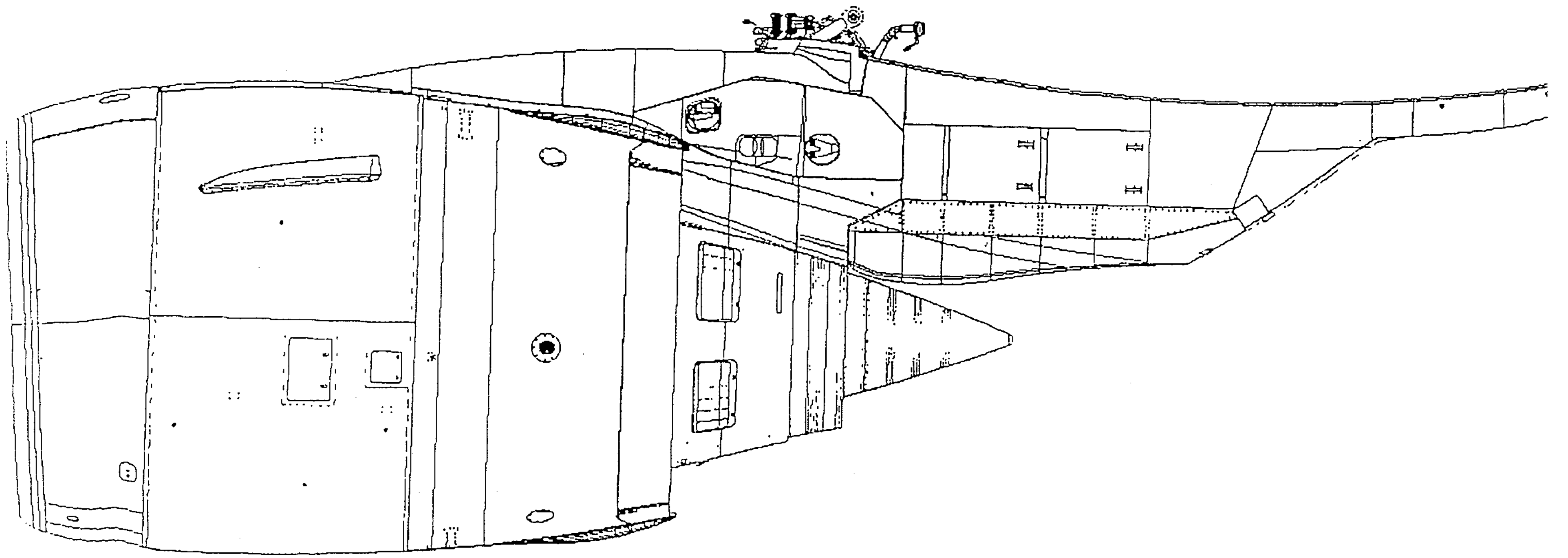




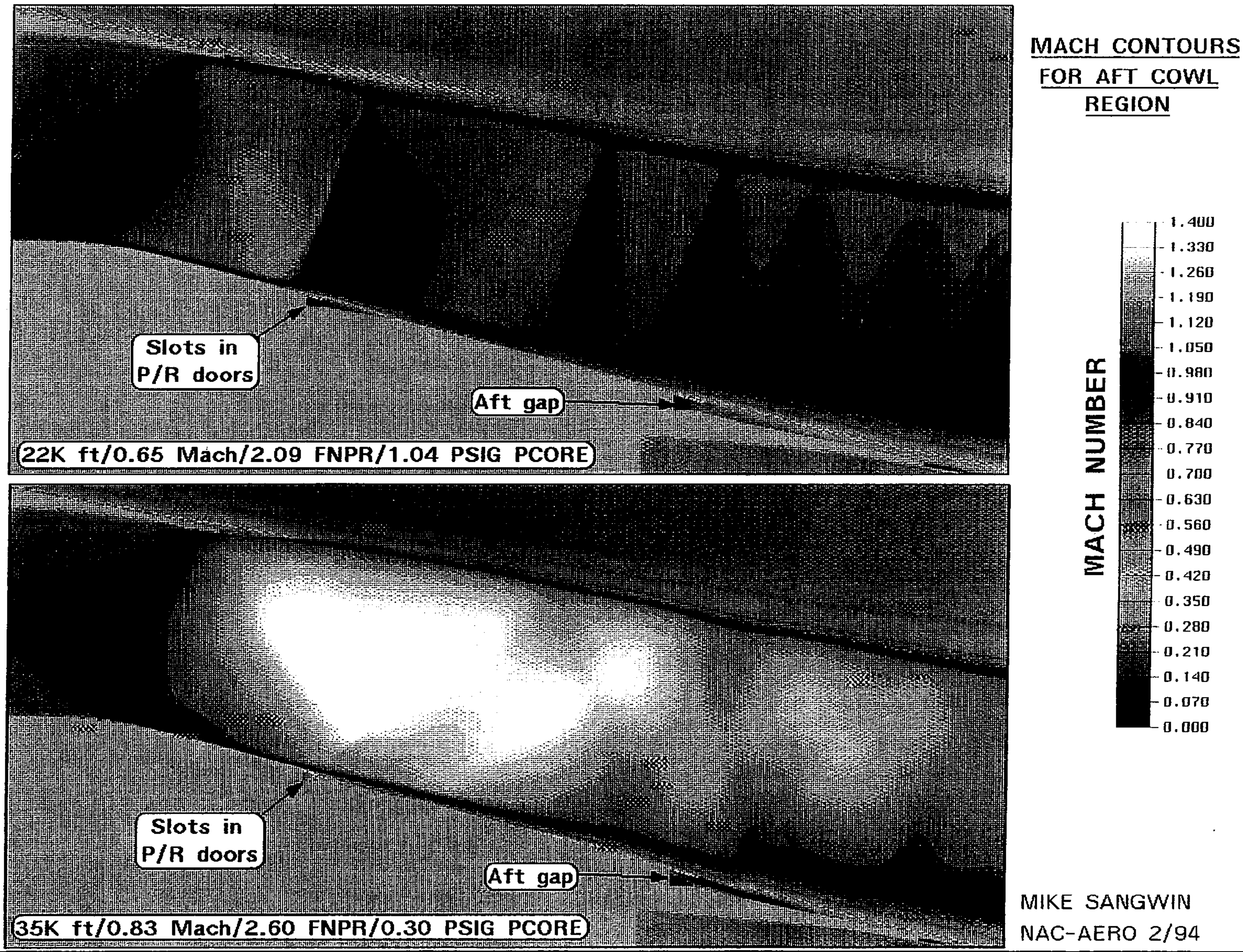
Analysis Constraints

- Engine Case Temperature
- Cowling Heat Transfer
- Ventilation Exit Flow Field
- Ventilation Inlet Configuration and performance
- Component Packing
- Computer Capability

TYPICAL PW4084 NACELLE INSTALLATION



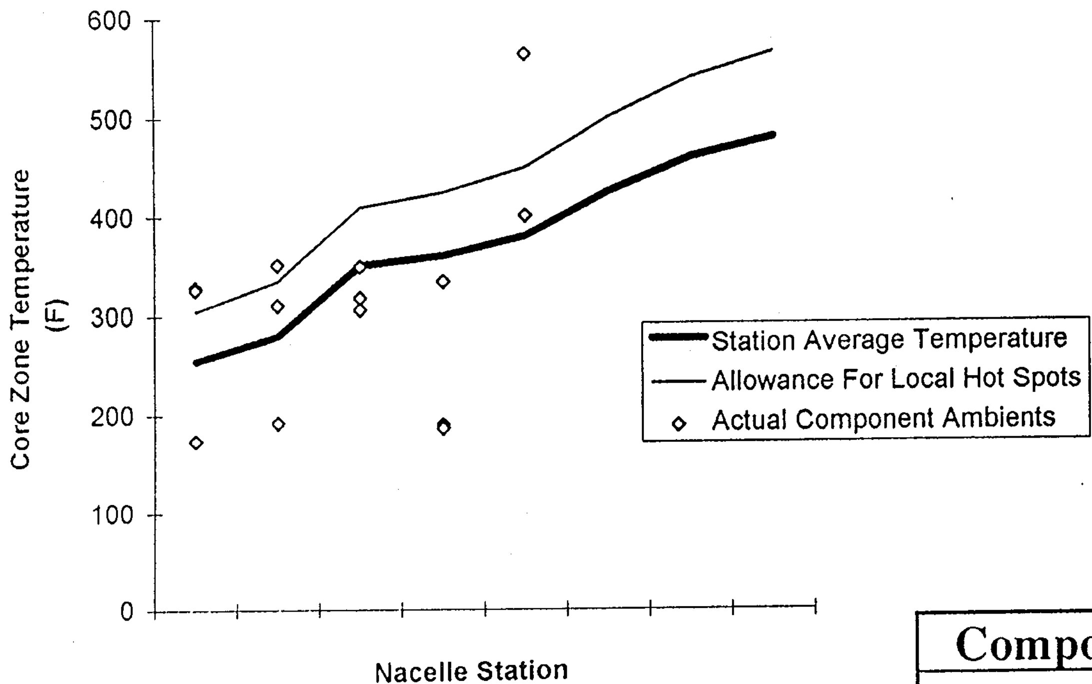
PW4084 CORE VENTILATION/EXHAUST SYSTEM ANALYSIS
PARC2D AXISYMMETRIC SIMULATIONS AT RA001 FTB CONDITIONS



MIKE SANGWIN
NAC-AERO 2/94

Figure 5

Component Cooling Results



Component Cooling Analysis Validity	
Engine	Number of 777 Tests To Resolve
A	7
B	5
C	3

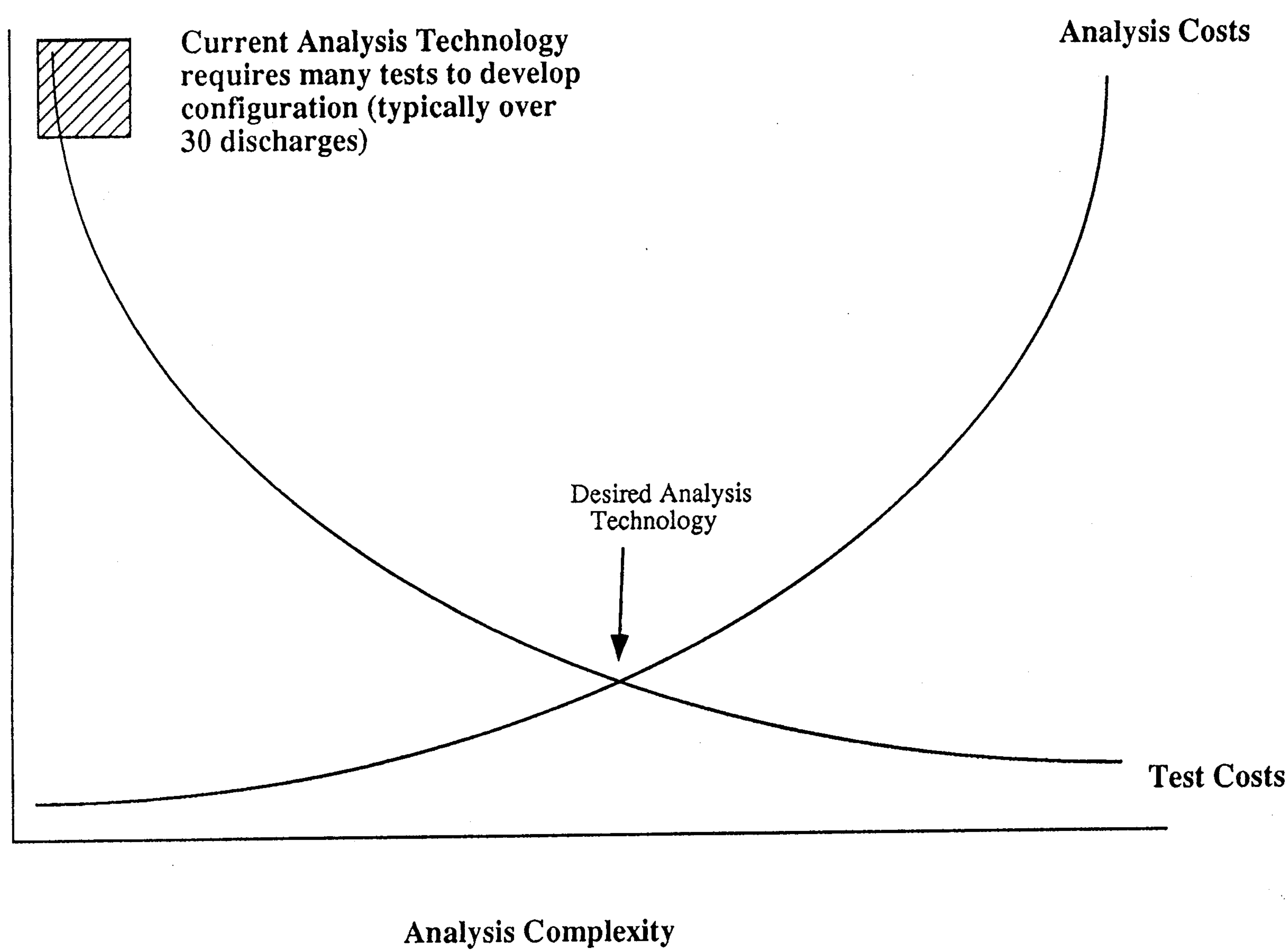
Challenge

Better predictive methods to reduce / eliminate tests.

FIRE EXTINGUISHING TESTS AND OPPORTUNITIES

- FAA has estimated that a typical Halon fire extinguishing certification consumes 150 - 200 sq. miles of ozone area.
- Boeing has developed a test agent substitute method to minimize environmental impact.
- Challenge is to predict by pre-test analysis that system works.
- Analysis challenges:
  - Computation methods and M/C time
  - Agent distribution in a complex zone
  - Transient behavior
  - Mixed flows (Agent, Nitrogen, Air)
  - Two phase flows.

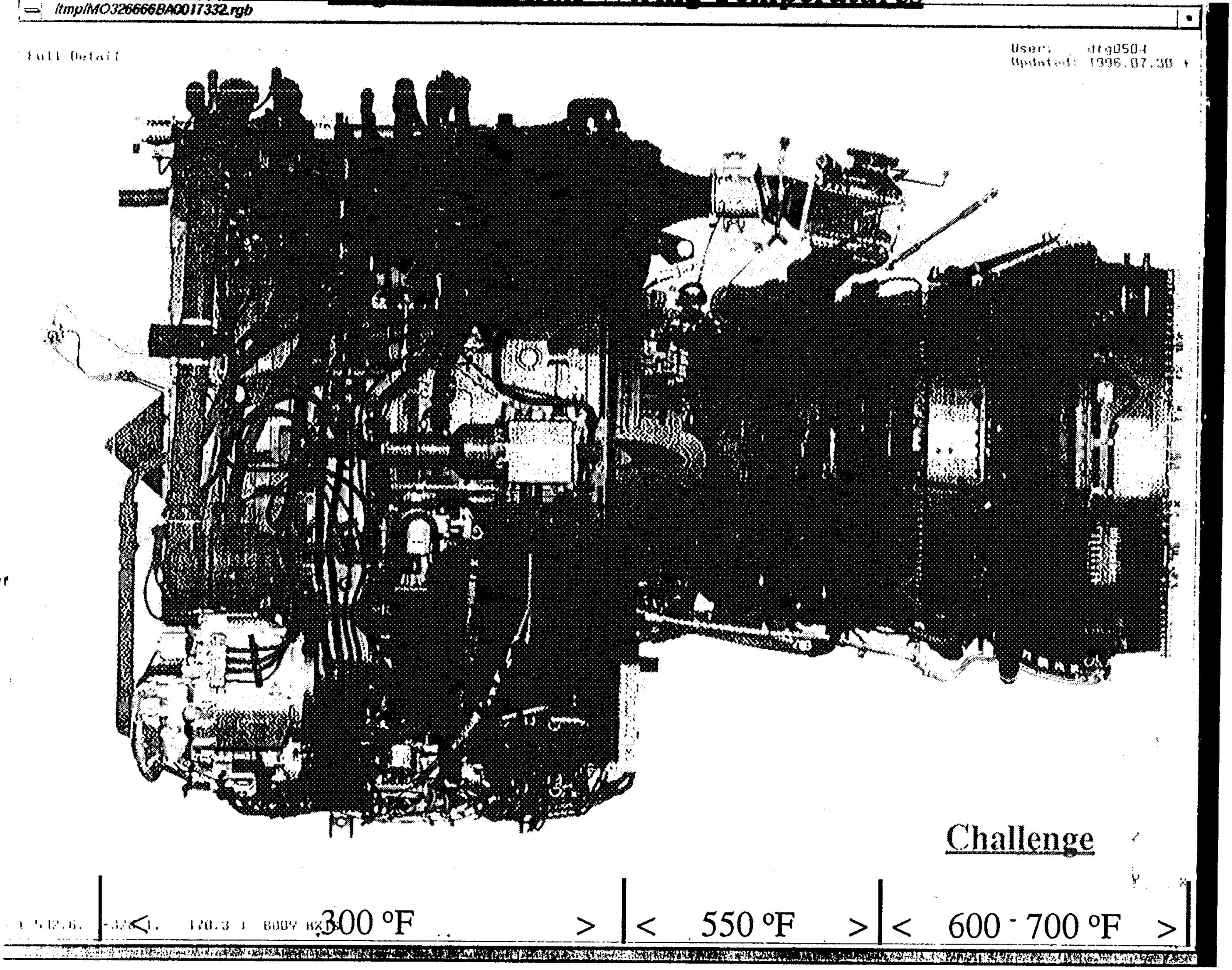
FIREX TEST COSTS



700°F WIRING AND CONNECTORS

- Traditional requirement for engine externals wiring is 550°F temperature exposure.
- Airlines are subject replacement of wiring and connectors at shop visits.
- New designs (e.g. 737-X) have met the challenge of environments up to 600°F.
- Future challenge is to develop 700°F wiring and connectors to accommodate predicted cycle temperatures.
- Boeing has an active IRD program, but a need exists for an industry initiative.

Engine Externals Wiring Temperatures



CONCLUSIONS

- Research community needs to review the opportunities outside the engine case.

- Airframers are meeting the challenges with expensive test and development programs. Analysis capability improvement will benefit the industry.